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Abstract: In response to a need for a safe and effective method of reducing rodent damage to newly planted corn in conservation-tillage fields, two chemicals, thiram (tetramethylthiuram disulfide) and methiocarb (3,5-dimethyl 1-4-[methylthio] phenol methylcarbamate), were coated on untreated seed corn for evaluation as repellents and agents for conditioned aversion. Results of field-enclosure and other studies indicate that 1.25% thiram by weight repels thirteen-lined ground squirrels (*Spermophilus tridecemlineatus*) and causes no phytotoxicity. Lower thiram rates tested (0.08, 0.4, 0.8%) were ineffective. Methiocarb rates of 2.5 and 5.0% repelled thirteen-lined ground squirrels, but these rates may significantly reduce corn stand counts under some conditions. Methiocarb at 0.5% appears ineffective. Although this rate was highly repellent on dry unplanted seeds, it lacked repellency with planted corn, possibly because of the way that ground squirrels attack water-soaked, germinated seeds. Preliminary laboratory trials, evaluating the response of deer mice (*Peromyscus maniculatus*) to repellent-treated corn seed, indicate that thiram (0.31, 1.25%), methiocarb (0.031, 0.5%), and a combination of the two, all repel deer mice, but that repellency does not persist when treated seeds are replaced with untreated. The negative-experience cue apparently was the treatment itself; no lasting aversion to untreated corn was produced. However, continued repellency was achieved using a methiocarb (0.125%)+odor treatment. With further development, repellents may provide an effective and safe solution for rodent damage to newly planted corn, an emerging problem for conservation-tillage agriculture.

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INTRODUCTION

Various rodents that thrive in conservation-tillage fields cause damage to corn in some years by digging and consuming newly planted seeds and kernels attached to seedlings. This damage, which occurs for approximately 3 weeks after planting, may result in stand losses of $\geq 25\%$ in some fields (Johnson et al. 1982), but average stand losses are lower and variable. Holm et al. (1983) and Holm (1984) reported mean corn stand losses in Nebraska of 4.7% (range: 0.3 - 10.5%) and 8.3% (range: 5.0 - 10.3%) in eastern and western Nebraska, respectively, in 1983, but < 1% overall in the same areas in 1984. Young (1984) reported losses in Iowa of 0.57% (range: 0 - 5.1%), although earlier observational reports from Iowa indicated rodent damage severe enough to necessitate replanting (Johnson et al. 1982).

On the beneficial side, these rodents consume weed seeds; crop-damaging insects (Zimmerman 1965, Whitaker 1966, Beasley and McKibben 1976, Holm 1984, Young 1984) including grasshoppers, wireworms, and cutworms (Gillette 1889, Orcutt and Aldrich 1892, Fitzpatrick 1925, Holm 1984); and waste grain that could produce unwanted volunteer crops during the following growing season. One cutworm may damage 3-4 corn seedlings (Archer and Musick 1977, Clement and McCartney 1982) so each cutworm consumed by rodents may represent saving of several corn plants.

Nationwide, conservation-tillage farming systems have increased markedly in recent years, totaling 39 million ha (30% of all cropland) in 1984 (Conserv. Tillage. Inf. Cent. 1985). Growth of these systems is expected to continue (USDA 1975, McCorkle 1981) and rodent damage problems are likely to increase accordingly. Control methods currently available are not satisfactory because their efficacy is unknown and/or they may cause hazards to non-target wildlife (Nason 1981). Additionally, lethal controls may reduce beneficial aspects of rodents that appear to have potential economic value.

Repellents coated on seed prior to planting offer one potential method of controlling this rodent damage. A substance may repel because it has an unpleasant odor or taste or because, in conjunction with a taste or other cue, it produces disagreeable post-ingestion effects (Hermann and Kolbe 1971, Rogers 1974). The latter is a form of conditioned aversion, a type of repellency that pairs a food, space, or an event (e.g. cue) with an aversive experience (e.g. post-ingestion discomfort) and leads to avoidance of that item in subsequent encounters (Dorrance and Gilbert 1977). Odor repellents are intended to repel target animals from a specific area. Examples include materials such as lion dung or blood meal to repel rabbits from a garden or mothballs to repel bats from an attic. Taste repellents make a potential food item distasteful; thiram is an example commonly used to prevent browsing damage to trees and shrubs. Methiocarb repels apparently because it has a taste or other cue that signals disagreeable post-ingestion effects (Rogers 1974) and seemingly is fast acting, an advantage in pairing the discomfort with the cause.

Use of repellent seed treatments may have several advantages. Public acceptance may be greater because repellents are relatively less toxic than rodenticides and are thus safer if accidently ingested. Furthermore, a resident "conditioned" population may prevent the immigration of naive individuals into the area while allowing any beneficial activities of the resident population to continue (Tevis 1956, Rogers 1978).

This paper presents an overview of studies conducted at the University of Nebraska to determine the efficacy and feasibility of using thiram or methiocarb seed treatments to reduce rodent damage to newly planted corn. Thiram is federally registered as a fungicide and repellent but the rate for use on seed corn is a low fungicide rate. In preliminary field use, thiram showed effective repellency of thirteen-lined ground squirrels (O. C. Burnside, pers. observ.). Methiocarb is an insecticide federally registered as a bird repellent for use on corn seed; in some states, it has Special Local Needs (24c) registration for use in controlling rodents in newly-planted corn. Our studies to date have included thirteen-lined ground squirrels and deer mice, two species implicated in the damage problem (Johnson et al. 1982, Holm 1984). Ground squirrels are often reported in damage complaints, possibly because they have fairly visible diurnal habits, and deer mice appear to be the most abundant rodent species in low-tillage fields in Nebraska (Holm 1984) and Iowa (Young 1984).

Thesis research by A. Koehler and B. Holm provided the basis for much of the repellency data reported in this paper. Thanks are extended to M. Beck, R. Case, B. Holm, and R. Timm for helpful comments on the manuscript, and to J. Andelt and P. Lionberger for typing and technical assistance.

METHODS

Initial evaluation of thirteen-lined ground squirrel response to repellent seed treatments was made in 1980 using laboratory feeding preference tests (Zurcher et al. 1983). Field and field-enclosure studies with ground squirrels were conducted from 1981 to 1984 at the Lincoln Agronomy Farm, Lincoln, Nebraska (Johnson et al. 1985). The field enclosures (13.7 x 6.4 x 1 m and 14.0 x 10.0 x 1 m) were a modification of a technique used by Linehan (1979) to test bird repellents. The technique allows greater control of variables that often cause problems in field evaluation of repellents.

Laboratory trials were conducted during 1984 and 1985 to determine the response of deer mice to repellent-treated corn and to evaluate various aspects of conditioned aversion (Holm et al. 1985; Holm, in preparation). These experiments consisted of two phases: training, and testing. During days 1-6 of an experiment, the training phase, deer mice received each day 25 corn seeds coated with their assigned treatments. From day 7 until termination of a trial, the testing phase, mice received each day 25 untreated, or in one trial odor-treated, corn seeds.

RESULTS

The laboratory feeding preference trials (Zurcher et al. 1983) showed that both thiram (0.08, 0.16, and 0.32% active ingredient by weight of corn seed) and methiocarb (0.5%) repelled thirteen-lined ground squirrels in two-choice tests. However, when offered only thiram-treated corn (0.08%) for 18 days, the test animals ate normal amounts and weight loss was not significant. When given only methiocarb-treated corn for 18 days, ground squirrels consumed minimal amounts and had significant weight losses.

Results of 5 field-enclosure trials (Johnson et al. 1985) again indicated that both chemicals tested do, at certain rates, repel thirteen-lined ground squirrels. Thiram coated on corn seed at 1.25% by weight of seed repelled ground squirrels in both trials (1982 and 1983) in which it was used; no phytotoxicity problems were observed at this rate (Koehler 1983). Lower thiram rates tested (0.08, 0.4, and 0.8%) were ineffective in repelling thirteen-lined ground squirrels.

Methiocarb rates of 2.5 and 5.0% were effective in repelling ground squirrels, but these rates may significantly reduce corn stand counts under some conditions (Koehler 1983). The lower methiocarb rate tested (0.5%), although found highly repellent to ground squirrels on dry unplanted seeds, did not repel ground squirrels in 4 of 5 field-enclosure trials. Addition of a sticker to this treatment in one trial (to ensure that rainfall was not washing off the methiocarb) did not increase effectiveness. Moreover, Johnson et al. (1985) report that 0.5% methiocarb-treated corn received significantly more damage than did controls in 2 trials.

Preliminary analyses of laboratory studies with deer mice indicate that thiram (0.31 and 1.25%), methiocarb (0.031 and 0.5%), and a combination of the two all repelled deer mice under laboratory conditions (Holm et al. 1985, Holm, in preparation). However, repellency did not persist when treated seeds were replaced with untreated (days 7-14), indicating that no lasting aversion to corn developed. The repellency cue apparently was the treatment itself. In subsequent studies (Holm, in preparation), methiocarb (0.125%)+odor-treated corn was offered to deer mice in the training phase (days 1-6) and odor-treated corn in the testing phase (days 7-18). Deer mice were repelled during the training phase (with methiocarb) and, in this experiment, repellency continued for 7 days of the testing phase (without methiocarb).

DISCUSSION

Thiram at the 1.25% rate appears effective in reducing thirteen-lined ground squirrel damage to newly-planted corn (Johnson et al. 1985). Moreover, thiram at approximately 2.5% has been used effectively to repel ground squirrels from corn research plots at the Lincoln Agronomy Farm for 4 years (O. C. Burnside, pers. observ.), and thiram repelled deer mice in laboratory studies (Holm et al., 1985; Holm, in preparation). No phytotoxic effects were observed at the 1.25 or 2.5% rates (Koehler 1983). However, further work with thiram is needed, particularly with deer mice in field situations and with other mammalian species present in conservation-tillage fields before it can be recommended for use to protect newly-planted corn.

The lower methiocarb rate tested (0.5%), a rate currently registered to prevent bird damage to newly-planted corn, lacked repellency in the field-enclosure trials possibly because of the way that ground squirrels attacked water-soaked, germinated seeds. When thirteen-lined ground squirrels dig and consume sprouted seeds, usually the seed coat is removed and left behind, perhaps removing the methiocarb treatment. With dry unplanted corn seeds, the seed coat remains intact. During two enclosure trials, this methiocarb treatment received more damage than did controls; Johnson et al. (1985) speculate that this may relate to interactions with other factors such as insects. Insects were found dead or dying at some 0.5% methiocarb-treated plots; insects affected by the methiocarb (an insecticide) treatment may have provided an attractive food source, thereby attracting ground squirrels to return to the methiocarb-treated plots. Although these results involving 0.5% methiocarb treatment initially appear discouraging, further work with this material is warranted. The enclosure trials involved only thirteen-lined ground squirrels; other rodents, because of their feeding behavior or other reasons, may respond differently.

Approximate costs for repellent treatments were calculated based on current retail costs for each chemical and on a planting rate of 11 kg of corn seed/ha (10 pounds/acre). The approximate cost for thiram at the 1.25% rate was $1.56/ha ($0.63/acre) and for methiocarb at the 0.5% rate, $3.46/ha ($1.40/acre).

The laboratory experiments with deer mice (Holm et al. 1984, Holm in preparation) found that feeding suppression (repellency) did not persist in any group when untreated seeds were offered, indicating that deer mice could distinguish between treated and untreated corn. The negative-experience cue apparently was the treatment itself; no lasting aversion to untreated corn developed. However, the experiment using an added odor cue indicates that further work with various cues or other aspects of repellency might sufficiently lengthen the suppressed feeding period. One implication is that adding an odor or other cue to methiocarb-treated corn may result in greater field effectiveness. If rodents learned at planting time to avoid corn seeds treated with methiocarb and odor, a persistant odor cue may be sufficient to prevent damage later after the seeds imbibe water.

Repellents that produce disagreeable post-ingestion effects (illness-producing) may have inherent taste, odor, or other cues to the post-ingestion discomfort (e.g. methiocarb, Rogers 1978) (Table 1). Other such repellents may be undetectable because they lack inherent cues, at least at some low rates that still produce discomfort and repellency (Bullard et al. 1983) or because the delivery makes the source undetectable [e.g. by injection in rodents (Stewart et al. 1983) or water bath in birds (Mason and Reidinger 1983)]. If an illness-producing repellent applied to a food is undetectable and the treated food is novel, the target animal will likely form an aversion to the novel food. However, if the repellent is undetectable and the food familiar, the target animal may form an aversion to a different, novel food that was consumed and may continue to consume the treated food. Undetectable, low treatment rates may cause mild discomfort but be insufficient to cause avoidance of a familiar food in the absence of an appropriate cue.

Different species of rodents and different individuals within a species may respond differently to cues, possibly because of different sensory abilities or other reasons (Dorrance and Gilbert 1977; Robbins 1980; Holm, in preparation). Addition of a novel cue to an illness-producing repellent treatment could better ensure detectability by all target animals, and should lead to avoidance of the repellent + cue-treated food and possibly to avoidance of the food treated only with the cue.

The presence of a cue may be important in protecting newly-planted corn from rodent damage because at least some of the rodents are likely to be familiar with the food needing protection, corn. Use of an inexpensive cue may allow use of low, otherwise possibly undetectable, repellent rates, thus leading to lower costs (Bullard et al. 1983). Moreover, rodents are more likely to continue eating post-harvest corn left on the soil surface, a benefit in some fieds, as well as continue other beneficial food habits (Rogers 1978). Similar scenarios may exist in other agricultural situations where the food needing protection is likely familiar to the target animals.

Overall, our experiments to date with repellent seed treatments are encouraging. Although further research is needed, results indicate that repellents, if understood and properly used, may provide an effective control for rodent damage in newly planted corn, while maintaining beneficial aspects of rodent populations in conservation-tilllage fields.

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Table 1. Characteristics of some repellency or learning procedures that may have implications for rodent control in newly planted corn.

Repellent Type	Repellent Characteristic[a]	Food Characteristic[b]	Expected Result[c]
disagreeable odor	detectable	novel or familiar	avoidance of specific areas
disagreeable taste	detectable	novel or familiar	avoidance of treated food
illness-producing	detectable	novel	avoidance of treated food; possible avoidance of untreated food because food cues may also be used
illness-producing	detectable	familiar	avoidance of treated food; would likely still consume untreated food
illness-producing	undetectable	novel	avoidance of treated and untreated food
illness-producing	undetectable	familiar	animal may continue to consume the familiar food; may form aversion to a different, novel food, recently consumed

[a]Detectable or undetectable by target species.
[b]Novel or familiar to target species.
[c]Expected results may vary with location of food (e.g. corn planted or in dish), animal experience (previous exposure to repellent), availability of alternate foods, strength of repellent or associated cue, or other factors (Dorrance and Gilbert 1977, Rogers 1978, Reidinger and Mason 1983).